



MOTOROLA

Motorola Paris-Saclay
Parc les Algorithmes
91193 Gif-sur-Yvette Cedex
France
Tel : +33/0 1 69 35 77 00
Fax : +33/0 1 69 35 77 01

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Europäisches Patentamt
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Allemagne

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INTERNATIONAL PATENT APPLICATION PCT/EP03/00596
OUR REF : CR00548P C01/MAW
In response to the Written Opinion of 17th October 2003

Dear Sirs

With reference to the **Written Opinion of 17th October 2003** and the communication of 23rd January 2004 extending the time limit for reply, the Applicant wishes to amend the claims of the application, with consequential amendments to the introduction, and herewith files new pages 3 to 5 and 17 to 22 to replace the corresponding pages 3 to 5 and 17 to 32 of the specification as filed, together with copies of the pages identifying the amendments made. In view of the extensive revision to the claims, the original claim numbering has been maintained in the copy identifying the amendments made, claim 22 having been renumbered as claim 1 in the new pages.

We believe that all the Examiner's objections have been met and allowance of the present application is respectfully requested. However, in the event that any other questions arise, the Examiner is invited to call the undersigned at +33 1 69 35 25 74.

The Applicant hereby authorises that in this application any fees and costs falling due be automatically debited from Deposit Account No. 28050071.

Martin WHARMBY
Senior Patent Attorney
for the Applicant

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for multiple antennas systems in the publication by G.J. Foschini and M.J. Gans, "On Limits of Wireless Communications in a fading Environment when Using Multiple Antennas", *Wireless Personal Communications* 5 6:311-335, 1998. However, it has been demonstrated (in the publication by P. Loubaton, M. Debbah and M. de Courville, "Spread OFDM Performance with MMSE Equalization", in *International Conference on Acoustics, Speech, and Signal Processing*, Salt Lake City, USA, May 10 2001) that V-BLAST algorithms are not suited for conventional SOFDM systems due to the averaging of the SNRs (signal/noise ratios) at the receiver across the carriers during the despreading step. Moreover, such approaches lead to a tremendous decoding complexity due 15 to the computation of several pseudo inverse matrices.

A need therefore exists for an OFDM communication system and decoding algorithm for use therein wherein the abovementioned disadvantage(s) may be alleviated.

20

Statement of Invention

~~In accordance with a first aspect of the present invention there is provided a spread OFDM wireless communication system as claimed in claim 1.~~

25

~~In accordance with a second aspect of the present invention there is provided a spread OFDM wireless communication system as claimed in claim 10.~~

30

~~In accordance with a third aspect of the present invention there is provided a receiver, for use in a spread OFDM wireless communication system, as claimed in claim 11.~~

5

~~In accordance with a fourth aspect of the present invention there is provided a receiver, for use in a spread OFDM wireless communication system, as claimed in claim 18.~~

10

~~In accordance with a fifth aspect of the present invention there is provided~~ The present invention provides a method of decoding a received spread OFDM wireless communication signal, of operating and a receiver comprising decoding means for decoding a received signal by such a method, in a spread OFDM wireless communication receiver, as described in the accompanying ~~elaimed in claims 19.~~

15

20

~~In accordance with a sixth aspect of the present invention there is provided a method, for performing minimum mean square error equalization in a spread OFDM wireless communication system, as claimed in claim 27.~~

25

~~In one aspect, the present invention provides a new, efficient yet simple, low complexity decoding algorithm for an enhanced OFDM modulator.~~

30

~~Preferably the OFDM modulator is based on a Walsh-Hadamard transform, allowing exploitation of the mathematical properties of a Walsh-Hadamard precoder.~~

In one ~~form~~ embodiment of the present invention, the ~~new~~ decoding algorithm ~~consists in~~ comprises splitting a received block into two equal parts, one of the parts
5 being decoded first and then subtracted from the received vector to suppress part of the interference and the other of the parts being decoded next. This iterative procedure can be further extended by successive block splitting and results in a multi-resolution decoding algorithm. An
10 attractive property of this algorithm is that although it still relies on the computation of pseudo-inverses, the expressions of these pseudo-inverses are easy to derive and may consist simply in the product of a diagonal matrix by a Walsh Hadamard transform. Thus, using Walsh
15 Hadamard spreading sequences, the inherent complexity penalty of a V-BLAST decoding schemes is simply removed. This allows a significant gain in performance (e.g., around 3-4dB compared to MMSE SOFDM) with only a modest increase in complexity, which motivates:

- 20 i) the use of such new modulation schemes in practice and
- ii) their proposal as a solution for future wireless LAN standards.

25 The following technical merits of the ~~new~~ multi-resolution decoding algorithm of this embodiment of the present invention can be highlighted:

- Low arithmetical complexity compared to existing SIC BLAST techniques with same or better performance.
- 30 • Flexibility and scalability of the method (it is possible to adjust the number of iterations to be

performed based on a performance/complexity tradeoff).

- Can be combined into all OFDM standards as a proprietary transmission mode (since it can be

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Claims

1. ~~A spread OFDM wireless communication system (100) comprising:~~
 - 5 ~~at a transmitter (110-140)~~
 ~~means for transmitting a spread OFDM signal;~~
~~at a receiver (160-180)~~
 ~~means for receiving the spread OFDM signal;~~
 ~~means for equalizing the spread OFDM signal~~ - 10 ~~means for splitting the equalized spread OFDM~~
 ~~signal into a first plurality of portions~~
 ~~including a first portion and a second portion;~~
 ~~means for making a decision on the second~~
 ~~portion to produce a decided second portion;~~ - 15 ~~means for subtracting the decided second~~
 ~~portion from the received spread OFDM signal to~~
 ~~produce a first difference signal; and~~
 ~~means for equalising and processing the first~~
 ~~difference signal to recover the first portion~~ - 20 ~~of the received signal in which interference~~
 ~~due to second portion interfering terms is~~
 ~~substantially reduced.~~
2. ~~The system of claim 1 further comprising:~~
 - 25 ~~at the receiver (160-180)~~
 ~~means for making a decision on the first~~
 ~~portion to produce a decided first portion;~~
 ~~means for subtracting the first portion from~~
 ~~the equalised spread OFDM signal to produce a~~ - 30 ~~second difference signal; and~~

means for equalising and processing the second
difference signal to recover the second portion
of the received signal in which interference
due to first portion interfering terms is
5 substantially reduced.

3. The system of claim 2 wherein the receiver (160-180)
further comprises means for repeating processing a
predetermined number of further times, with the recovered
10 first and second portions in place of the decided first
and second portions, to recover more reliable estimates
for the first and second portions.

4. The system of claim 1, 2 or 3 further comprising:
15 at the receiver (160-180)
means for splitting the recovered received
signal into a second plurality of portions
greater in number than the first plurality of
portions and including a first subsequent
20 portion, a second subsequent portion, a third
portion and a fourth portion;
means for subtracting the second subsequent
portion, the third portion and the fourth
portion from the received signal to produce a
25 first subsequent difference signal; and
means for processing the first subsequent
difference signal to recover the first
subsequent portion of the recovered received
signal in which interference due to second,
30 third and fourth portion interfering terms is
substantially reduced;

~~means for making a decision on the first
subsequent portion to produce a decided first
subsequent portion;~~
~~means for subtracting the first subsequent~~
5 ~~portion, the third portion and the fourth~~
~~portion from the received signal to produce a~~
~~second subsequent difference signal; and~~
~~means for processing the second subsequent~~
~~difference signal to recover the second~~
10 ~~subsequent portion of the recovered received~~
~~signal in which interference due to first,~~
~~third and fourth portion interfering terms is~~
~~substantially reduced;~~
~~means for making a decision on the second~~
15 ~~subsequent portion to produce a decided second~~
~~subsequent portion;~~
~~means for subtracting the first subsequent~~
~~portion, the second subsequent portion and the~~
~~fourth portion from the received signal to~~
20 ~~produce a third difference signal;~~
~~means for processing the third difference~~
~~signal to recover the third portion of the~~
~~recovered received signal in which interference~~
~~due to first, second and fourth portion~~
25 ~~interfering terms is substantially reduced;~~
~~means for making a decision on the third~~
~~portion to produce a decided third portion;~~
~~means for subtracting the first subsequent~~
~~portion, the second subsequent portion and the~~
30 ~~third portion from the received signal to~~
~~produce a fourth difference signal;~~

~~means for processing the fourth difference
signal to recover the fourth portion of the
recovered received signal in which interference
due to first, second and third portion
5 interfering terms is substantially reduced; and
means for making a decision on the fourth
portion to produce a decided fourth portion.~~

~~5. The system of claim 4 wherein the receiver (160-180)
10 further comprises means for repeating processing a
predetermined number of further times, with the decided
first subsequent portion, the decided second subsequent
portion, the decided third portion and the decided fourth
15 portion in place of the recovered first subsequent
portion, the recovered second subsequent portion, the
recovered third portion and the recovered fourth portion
respectively, to recover more reliable estimates for the
first subsequent portion, the second subsequent portion,
the third portion and the fourth portion.~~

20

~~6. The system of claim 4 wherein the second plurality
of portions is an integer multiple of 2 that is greater
than 2.~~

25

~~7. The system of any preceding claim wherein the means
for equalising and processing comprises:~~

~~first matrix multiplication means for multiplying by
a first diagonal matrix having elements dependent on
channel coefficients; and~~

~~second matrix multiplication means for multiplying
by a second matrix which is a subset of a Walsh
Hadamard matrix.~~

- 5 ~~8. The system of any preceding claim wherein the means
for equalising and processing comprises means for
performing minimum mean square error equalization.~~
- 10 ~~9. The system of any preceding claim wherein the means
for transmitting a spread OFDM signal comprises means for
spreading by performing a Walsh Hadamard transform.~~

~~10. A spread OFDM wireless communication system (100) comprising:~~

~~at a transmitter (110-140)~~

~~means for transmitting a spread OFDM signal;~~

5 ~~at a receiver (160-180)~~

~~means for performing minimum mean square error equalization having:~~

10 ~~first matrix multiplication means for multiplying by a first diagonal matrix having elements dependent on channel coefficients; and~~
~~second matrix multiplication means for multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.~~

11. A receiver (160-180) for use in a spread OFDM wireless communication system (100), the receiver comprising:

5 means for receiving a ~~wireless~~ spread OFDM wireless communication signal, and decoding means for decoding the received signal by a method as claimed in any of claims 20 to 25, said decoding means comprising:

10 equalizing and decision means for performing said equalizing and decision function on the received spread OFDM signal (y),
means for splitting the equalized and decided spread OFDM signal block (\hat{s}) into a number 2^i
first plurality of portions ($\hat{s}_1, \hat{s}_2, \hat{s}_3, \hat{s}_4$),
where i is positive integer ~~including a first~~
15 ~~portion and a second portion;~~

characterised by:
~~means for making a decision on the second~~
~~portion to produce a decided second portion;~~
subtracting means for subtracting, for each of
20 said portions (\hat{s}_1) of the equalized and decided

signal block in turn, said values ($M \begin{bmatrix} 0 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \end{bmatrix}$)

derived from the decided ~~second~~ other portions
(\hat{s}_2 to \hat{s}_4) of the equalized and decided signal
block from the received ~~spread OFDM~~ signal
25 block (y) to produce a ~~first~~ respective
difference signal; and

said equalizing and decision means being
arranged to perform said
~~means for equalising and decision function on~~
~~processing the first respective difference~~
5 signal to produce said further processed
equalized and decided ~~recover the first portion~~
(\hat{s}_1) of the received signal in which of
interference due to second the other portions
(\hat{s}_2 to \hat{s}_4) of the equalized and decided signal
10 block interfering terms is substantially
reduced;
and said decoding means being arranged to
repeat, for each of the other portions (\hat{s}_2 , \hat{s}_3 ,
 \hat{s}_4) of the signal block, said steps of
15 producing the respective difference signal and
performing the equalising and decision function
to produce the further processed equalized and
decided portion.

20 12. ~~The A receiver of as claimed in claim 11 further~~
~~comprising:~~
~~means for making a decision on the first portion to~~
~~produce a decided first portion;~~
25 wherein said subtracting means for is arranged
so that repeating subtracting the first values
derived from the other portions of from the
equalised spread OFDM and decided signal block
from the received signal to produce a second
respective further difference signal; and

means for equalising and processing the second
difference signal to recover the second portion
of the received signal in which interference
due to first portion interfering terms is
substantially reduced comprises subtracting
values derived from at least one of said
further processed portions (\hat{s}_2 to \hat{s}_4) of the
received signal from the received spread OFDM
signal (y).

10

13. ~~The A receiver of as claimed in claim 11 or 12~~
wherein ~~the receiver further comprises~~ said decoding means
for repeating is arranged to iterate processing the
signal block, including iterating the steps of producing
the respective difference signal and performing the
equalising and decision function to produce the further
processed equalized and decided portion with values
derived from the further processed ~~a predetermined number~~
~~of further times, with the recovered first and second~~
portions (\hat{s}_1 to \hat{s}_4) in place of the ~~decided first and~~
~~second previously processed portions~~ (\hat{s}_1 to \hat{s}_4), to recover
still more reliable estimates for each of the first and
second portions.

14. ~~The receiver of claim 11, 12 or 13 further~~
~~comprising:~~
~~means for splitting the recovered received signal into a~~
~~second plurality of portions greater in number than the~~
~~first plurality of portions and including a first~~

~~subsequent portion and a second subsequent portion, a
third portion and a fourth portion;~~

5 ~~means for subtracting the second subsequent
portion, the third portion and the fourth
portion from the recovered received signal to
produce a first subsequent difference signal;~~
and

10 ~~means for processing the first subsequent
difference signal to recover the first
subsequent portion of the recovered received
signal in which interference due to second,
third and fourth portion interfering terms is
substantially reduced;~~

15 ~~means for making a decision on the first
subsequent portion to produce a decided first
subsequent portion;~~

20 ~~means for subtracting the first subsequent
portion, the third portion and the fourth
portion from the received signal to produce a
second subsequent difference signal;~~

25 ~~means for processing the second subsequent
difference signal to recover the second
subsequent portion of the recovered received
signal in which interference due to first,
third and fourth portion interfering terms is
substantially reduced;~~

30 ~~means for making a decision on the second
subsequent portion to produce a decided second
subsequent portion;~~

~~means for subtracting the first subsequent
portion, the second subsequent portion and the~~

~~fourth portion from the received signal to
produce a third difference signal;
means for processing the third difference
signal to recover the third portion of the
5 recovered received signal in which interference
due to first, second and fourth portion
interfering terms is substantially reduced;
means for making a decision on the third
portion to produce a decided third portion;
10 means for subtracting the first subsequent
portion, the second subsequent portion and the
third portion from the received signal to
produce a fourth difference signal;
means for processing the fourth difference
15 signal to recover the fourth portion of the
recovered received signal in which interference
due to first, second and third portion
interfering terms is substantially reduced; and
means for making a decision on the fourth
20 portion to produce a decided fourth portion.~~

15. The A receiver of as claimed in claim 134 wherein
said decoding means is arranged so that iterating
processing the signal block includes splitting the
25 equalized and decided spread OFDM signal block (\hat{s}) into a
number 2^j of portions (\hat{s}_1 to \hat{s}_4), where j is positive
integer greater than i so that iterating the steps of
producing the respective difference signal and performing
the equalising and decision function to produce the
30 further processed portion is performed with a greater
number of portions than the previous steps.~~further~~

~~comprising means for repeating processing a predetermined
number of further times, with the decided first
subsequent portion, the decided second subsequent
portion, the decided third portion and the decided fourth
5 portion in place of the recovered first subsequent
portion, the recovered second subsequent portion, the
recovered third portion and the recovered fourth portion
respectively, to recover more reliable estimates for the
first subsequent portion, the second subsequent portion,
10 the third portion and the fourth portion.~~

16. ~~The A receiver of as claimed in any one of claims
11- to 15 wherein the said equalizing and decision means
for equalising and processing comprises:~~
15 ~~first~~ matrix multiplication means for multiplying by
a first diagonal matrix having elements dependent on
channel coefficients, and
~~second matrix multiplication means for multiplying~~
by a second matrix which is a subset of a Walsh
20 Hadamard matrix.

17. ~~The A receiver of as claimed in any one of claims
11- to 16 wherein the said equalizing and decision means
for equalising and processing comprises means for
25 performing minimum mean square error equalization.~~

~~18. A receiver (160-180) for use in a spread OFDM
wireless communication system, the receiver comprising:
means for performing minimum mean square error
equalization having:~~

5 ~~first matrix multiplication means for
multiplying by a first diagonal matrix having
elements dependent on channel coefficients; and
second matrix multiplication means for
multiplying by a second matrix which is a~~
10 ~~subset of a Walsh Hadamard matrix.~~

19. ~~A method of operating a receiver (160-180) in a spread OFDM wireless communication system (100), the method comprising:~~

5 ~~receiving a wireless spread OFDM signal;~~
 ~~equalizing the spread OFDM signal~~
 ~~splitting the equalized spread OFDM signal into~~
 ~~a first plurality of portions including a first~~
 ~~portion and a second portion;~~
 ~~making a decision on the second portion to~~
10 ~~produce a decided second portion;~~
 ~~subtracting the decided second portion from the~~
 ~~received spread OFDM signal to produce a first~~
 ~~difference signal; and~~
 ~~equalising and processing the first difference~~
15 ~~signal to recover the first portion of the~~
 ~~received signal in which of interference due to~~
 ~~second portion interfering terms is~~
 ~~substantially reduced.~~

20 20. ~~The~~ A method of ~~as claimed in claim 19-22 wherein~~
 ~~further comprising:~~

~~making a decision on the first portion to~~
 ~~produce a decided first portion;~~
 ~~repeating~~ subtracting the first values derived
25 ~~from other portions of the equalized and~~
 decided signal block from the received
 ~~equalised spread OFDM signal to produce a~~
 ~~second~~ respective further difference signal;
 ~~and~~
30 ~~equalising and processing the second difference~~
 ~~signal to recover the second portion of the~~

received signal in which interference due to
first portion interfering terms is
substantially reduced comprises subtracting
values derived from at least one of said
5 further processed portions (\hat{s}_2 to \hat{s}_4) of the
received signal from the received spread OFDM
signal (y).

21. The A method of ~~as claimed in claim 22 or 20~~ further
10 comprising iterating processing the signal block,
including iterating the steps of producing the respective
difference signal and performing the equalising and
decision function to produce the further processed
equalized and decided portion~~repeating processing a~~
15 ~~predetermined number of further times,~~ with values
derived from the recovered further processed first and
second portions (\hat{s}_1 to \hat{s}_4) in place of the decided
previously processed first and second portions (\hat{s}_1 to \hat{s}_4),
to recover still more reliable estimates for each of the
20 ~~first and second portions.~~

22. The A method of ~~comprising claim 19, 20 or 21~~ further
comprising:
performing an equalizing and decision function
25 on the received spread OFDM signal (y),
splitting the equalized and decided spread OFDM
recovered received signal block (\hat{s}) into a
second plurality of portions greater in number
 2^i of than the first plurality of portions and

~~including a first subsequent portions ($\hat{s}_1, \hat{s}_2, \hat{s}_3, \hat{s}_4$) and a second subsequent portion, a third portion and a fourth portion, where i is~~
positive integer;

5 characterised by:

for each of said portions (\hat{s}_i) of the equalized
and decided signal block in turn subtracting

values ($M \begin{bmatrix} 0 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \end{bmatrix}$) derived from the second other

10 subsequent portions (\hat{s}_2 to \hat{s}_4) of the equalized
and decided signal block, the third portion and
the fourth portion from the recovered received
signal block (y) to produce a first respective
subsequent-difference signal; and

15 processing performing an equalising and
decision function on the first respective
subsequent-difference signal to recover the
first subsequent produce a further processed
equalized and decided portion (\hat{s}_1) of the
recovered received signal in which interference
20 due to the other second, third and fourth
portion interfering term portions (\hat{s}_2 to \hat{s}_4) of
the equalized and decided signal block is
substantially reduced;

25 making a decision on the first subsequent
portion to produce a decided first subsequent
portion;

the steps of producing the ~~subtracting the~~
first subsequent portion, the third portion and
the fourth portion from the received signal to
produce a second subsequent respective
5 difference signal and performing the equalising
and decision function to produce the further
processed equalized and decided portion being
repeated for each of the other portions (\hat{s}_2 , \hat{s}_3 ,
 \hat{s}_4) of the signal block.

10 ~~processing the second subsequent difference~~
~~signal to recover the second subsequent portion~~
~~of the recovered received signal in which~~
~~interference due to first, third and fourth~~
~~portion interfering terms is substantially~~
15 ~~reduced;~~
~~making a decision on the second subsequent~~
~~portion to produce a decided second subsequent~~
~~portion;~~
~~subtracting the first subsequent portion, the~~
20 ~~second subsequent portion and the fourth~~
~~portion from the received signal to produce a~~
~~third difference signal;~~
~~processing the third difference signal to~~
~~recover the third portion of the recovered~~
25 ~~received signal in which interference due to~~
~~first, second and fourth portion interfering~~
~~terms is substantially reduced;~~
~~means for making a decision on the third~~
~~portion to produce a decided third portion;~~

means for subtracting the first subsequent
portion, the second subsequent portion and the
third portion from the received signal to
produce a fourth difference signal;
5 processing the fourth difference signal to
recover the fourth portion of the recovered
received signal in which interference due to
first, second and third portion interfering
terms is substantially reduced; and
10 making a decision on the fourth portion to
produce a decided fourth portion.

23. The A method of as claimed in claim 21 further
comprising repeating wherein iterating processing the
15 signal block includes splitting the equalized and decided
spread OFDM signal block (\hat{s}) into a number 2^j of portions
(\hat{s}_1 to \hat{s}_4), where j is positive integer greater than i so
that iterating the steps of producing the respective
difference signal and performing the equalising and
20 decision function to produce the further processed
portion is performed with a greater number of portions
than the previous steps. ~~a predetermined number of further~~
~~times, with the decided first subsequent portion, the~~
~~decided second subsequent portion, the decided third~~
25 ~~portion and the decided fourth portion in place of the~~
~~recovered first subsequent portion, the recovered second~~
~~subsequent portion, the recovered third portion and the~~
~~recovered fourth portion respectively, to recover more~~
~~reliable estimates for the first subsequent portion, the~~
30 ~~second subsequent portion, the third portion and the~~
~~fourth portion.~~

~~24. The method of claim 22 wherein the second plurality of portions is an integer multiple of 2 that is greater than 2.~~

5

~~25. The A method of as claimed in any one of claims 19- to 24 comprising:~~

~~wherein said equalizing steps comprise multiplying by a first diagonal matrix having elements dependent on~~

10 ~~channel coefficients; and~~

~~multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.~~

~~26. The A method as claimed in of any one of claims 19 to 25 wherein said equalizing steps comprise~~
15 ~~performing minimum mean square error equalization.~~

~~27. A method for performing minimum mean square error equalization in a spread OFDM wireless communication system (100), the method comprising:~~
20

~~multiplying by a first diagonal matrix having elements dependent on channel coefficients; and~~
~~multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.~~

25